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Temporal dynamics of relief in avoidance conditioning and fear extinction: Experimental validation and clinical relevance

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ABSTRACT

The learning principles that guide the acquisition and extinction of avoidance are not fully understood. We developed a novel paradigm to study the temporal dynamics of relief, a putative reinforcer of avoidance, and the recovery of fear and avoidance following extinction. During conditioning, the avoidance action canceled the aversive unconditional stimulus (US), without terminating the predictive conditional stimulus (CS). Relief pleasantness was rated after fixed CS offsets, when US omission occured. Avoidance was effective to one CS, but not to another, to track stimulus-specific avoidance learning. Fear was extinguished under response prevention in a separate context. Recovery tests took place 24 h later, in both contexts and with a monetary cost added to the avoidance action. We found that avoidance gradually became stimulus-specific during conditioning, but hardly recovered during delayed testing. Across all phases, initial omissions of the aversive US triggered relief that gradually declined over consecutive omissions, in line with a theoretical prediction error signal. Participants that scored low on distress tolerance, however, displayed sustained levels of relief over continuous omissions. We propose that such forms of sustained relief may produce over-reinforcement of foregoing avoidance actions and promote the development of pathological avoidance. The current paradigm represents an efficacious tool to study the temporal dynamics of relief across avoidance learning and fear extinction and to characterize relief dysregulations in relation to psychopathology.

1. Introduction

Problematic fear and avoidance are two cardinal symptoms that cut across the anxiety disorders, and extend to post-traumatic stress disorder and obsessive-compulsive disorder (American Psychiatric Association, 2013). While fear and its extinction have been the core focus of clinical and pre-clinical anxiety research for decades (see Milad & Quirk, 2012; Vervliet, Craske, & Hermans, 2013; Vervliet, Baeyens, Van den Bergh, & Hermans, 2013), research on avoidance is only starting to catch up. One reason for studying avoidance in its own right is that avoidance is not merely a by-product of fear. Levels of fear and avoidance can co-vary, vary inversely, or vary independently in anxiety patients (Rachman & Hodgson, 1974), and avoidance behaviors often persist in the absence of any measurable fear reaction in animals (Mineka, 1979). Avoidance behaviors can even survive fear extinction (Bravo-Rivera, Roman-Ortiz, Montesinos-Cartagena, & Quirk, 2015; Vervliet & Indekeu, 2015). Hence, changing avoidance behavior seems to require more than changing fear response alone (see Arnaudova, Kindt, Fanselow, & Beckers, 2017; Treanor & Barry, 2017). Also, the mechanism that pushes adaptive into maladaptive avoidance remains largely unknown. There is a pressing need for human avoidance paradigms that can help identifying mechanistic deficits that underly pathological avoidance in patients with anxiety-related disorders. For that purpose, we tested in healthy individuals a newly developed paradigm to study relief as a putative reinforcer of avoidance and to probe the recovery of fear and avoidance following extinction.

Relief is a positive emotion that is triggered during unexpected omissions of a negative event (Deutsch, Smith, Kordts-Freudinger, & Reichardt, 2015; Vlemincx et al., 2009). Thus, relief can be understood as a 'pleasant surprise', comparable to the sudden receipt

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of a positive reward (Leknes, Lee, Berna, Andersson, & Tracey, 2011). In reinforcement learning algorithms, 'pleasant surprise' is formalized as the valence-signed prediction error (PE), the difference between expected reward and actual reward. It serves as the critical teaching signal for reinforcement learning that promotes repetition of the foregoing action to maximize future rewards (Sutton & Barto, 1998). In the case of relief, the 'pleasant surprise' is formalized as the difference between expected punishment and its actual omission, which reinforces the foregoing avoidance action in order to minimize future punishments (Maia, 2010; Moutoussis, Bentall, Williams, & Dayan, 2008). Specifically, the PE signal is thought to govern the rate of action-safety learning, in which the avoidance action becomes associated with its safety consequences in order to promote selection of this avoidance action during similar motivational states in the future (when safety is desired). Eventually, when the safety consequences are fully anticipated, omissions of punishment no longer trigger 'pleasant surprise' (reward PE). It follows that the PE is assumed to be high during initial avoidance learning instances and to gradually decrease over consecutive avoidance instances (Maia, 2010; Moutoussis et al., 2008).

An unexplored question is how action-safety learning develops in patients with anxiety disorders, and how this impacts the temporal dynamics of the 'pleasant surprise' PE. Laboratory studies have shown that anxiety patients are generally impaired in safety-signal learning, namely, learning which stimuli predict safety (Briscione, Jovanovic, & Norrholm, 2014; Duits et al., 2015). If these impairments generalize to action-safety learning in avoidance, omissions of punishment (i.e., safety) would remain somewhat unexpected and continuously trigger a 'pleasant surprise' PE. We propose that these continuous reinforcements give way to a habitization of the avoidance action, by which it becomes a behavioral routine that is disconnected from current goals and motivational states and is therefore more resistant to change (Gillan et al., 2014). In particular, we hypothesize that impaired learning of the action-safety association produces continuous reinforcements that promote the development of an association between the CS and the action instead. This association does promote repetition of the avoidance action to minimize future punishments, but in an inflexible manner that may develop into the unproductive/unnecessary avoidance behaviors that characterize anxiety disorders. This type of stimulus-response learning may be intact in anxiety patients, as it does not relie on an ability to learn to predict safety. In summary, we propose that safety-learning impairments may push adaptive, goal-directed avoidance into maladaptive, habitual avoidance through a dysregulation of PE signaling.

Current avoidance paradigms are not designed to study the interplay between safety learning and PE signaling in avoidance (but see Eldar, Hauser, Dayan, & Dolan, 2016, for a decision-making study that focused on neural PE signaling in avoidant decision-making). Some avoidance paradigms track emotional learning processes *before* each avoidance action (at CS onsets), which focuses on the role of CS-induced fear and/or expected controllability, but not on avoidance-induced safety or relief (e.g., van Meurs, Wiggert & Lissek; Delgado, Jou, LeDoux, & Phelps, 2009). Other paradigms do not signal the US (e.g., Collins, Mendelsohn, Cain, & Schiller, 2014), use very brief CS presentations (Gillan et al., 2014), or terminate the CS upon avoidance actions (mostly used in animal studies, e.g., Moscarello & LeDoux, 2013). These procedures make it difficult to disentangle avoidance-induced safety from omission-induced relief. Hence, although these paradigms contribute importantly to the study of avoidance, they are not ideally suited for detailed examination of the temporal dynamics of relief. In addition, most avoidance studies have focused on the conditioning of avoidance per se, leaving the extinction and recovery of avoidance behavior relatively unexplored in human research (but see Vervliet & Indekeu, 2015; Schlund, Brewer, Richman, Magee, & Dymond, 2015; Cameron, Schlund, & Dymond, 2015).

The current study tested in healthy individuals a newly developed protocol to track the temporal dynamics of relief and to probe the recovery of fear and avoidance. For that purpose, we integrated an avoidance protocol previously developed by Vervliet and Indekeu (2015) with a well-established fear extinction /recovery paradigm (Milad, Orr, Pitman, & Rauch, 2005), and added subjective ratings of relief pleasantness on a trial-by-trial basis (Leknes et al., 2011). Of note, CS durations were always fixed, irrespective of avoidance actions. This allowed Vervliet and Indekeu (2015) to track action-safety learning, as evidenced by gradual decreases in threat-expectancy and skin conductance reactivity immediately *after* each avoidance action but *before* CS offset. In the novel protocol, we added a relief pleasantness rating scale *after* each CS offset, when US omission occurred (Fig. 1A). We explicitly asked for the *pleasantness* of relief to probe the rewarding experience of 'pleasant surprise' as the valence-signed PE signal that is thought to reinforce avoidance actions (reinforcement learning; Moutoussis et al., 2008). In support, relief pleasantness ratings during unexpected omissions of pain were previously found to correlate with activations in the ventral striatum, a key node of reward prediction error processing (Leknes et al., 2011).

We also added an extra CS to the experimental design (Fig. 1B), in line with the original extinction paradigm (Milad et al., 2005). The avoidance action did not cancel the aversive US to this CS (CS+UU, the *unproductive* CS+, in contrast to CS+EE, the *effective* CS+; see also Schlund et al., 2015). Avoidance actions to a CS- that was never followed by the aversive US were *unnecessary*. This allowed us to track the differential development of effective, unproductive, and unnecessary avoidance actions. In addition, because only CS+EE underwent fear extinction on day 1, CS+UU served as a comparison for extinction tests on day 2 (cf. Milad et al., 2005). Finally, we inserted a context change between avoidance conditioning and fear extinction, and we tested fear, avoidance and relief in both contexts 24 h later. This allowed us to explore the ability of fear extinction to reduce avoidance actions within both the extinction and conditioning context, and to examine the interplay with fear and relief. Of note, a small monetary cost was added to each avoidance action during these tests, in order to explore effects of increased response costs on continued avoidance.

Anxiety- and avoidance-related personality traits have been found to correlate with avoidance frequency in other paradigms (trait anxiety, Vervliet & Indekeu, 2015; neuroticism, Lommen, Engelhard, & van den Hout, 2010; experiential avoidance, van Meurs, Wiggert, Wicker, & Lissek, 2014). In the current study, we wanted to explore individual differences in the regulation of relief. For that purpose, we focused on distress tolerance, a transdiagnostic risk factor that represents one's ability to experience and endure negative emotional states (Simons & Gaher, 2005) and that is associated with a broad range of anxiety symptomatology independent of general negative affect (Keough, Riccardi, Timpano, Mitchell, & Schmidt, 2010). Because individuals with lower levels of distress tolerance may find anticipation and endurance of the aversive US more taxing, we hypothesized that these individuals would experience more relief in reaction to US omissions. To the extent that relief pleasantness reinforces avoidance, lower tolerance of distress would also spur increased engagement in avoidance actions.

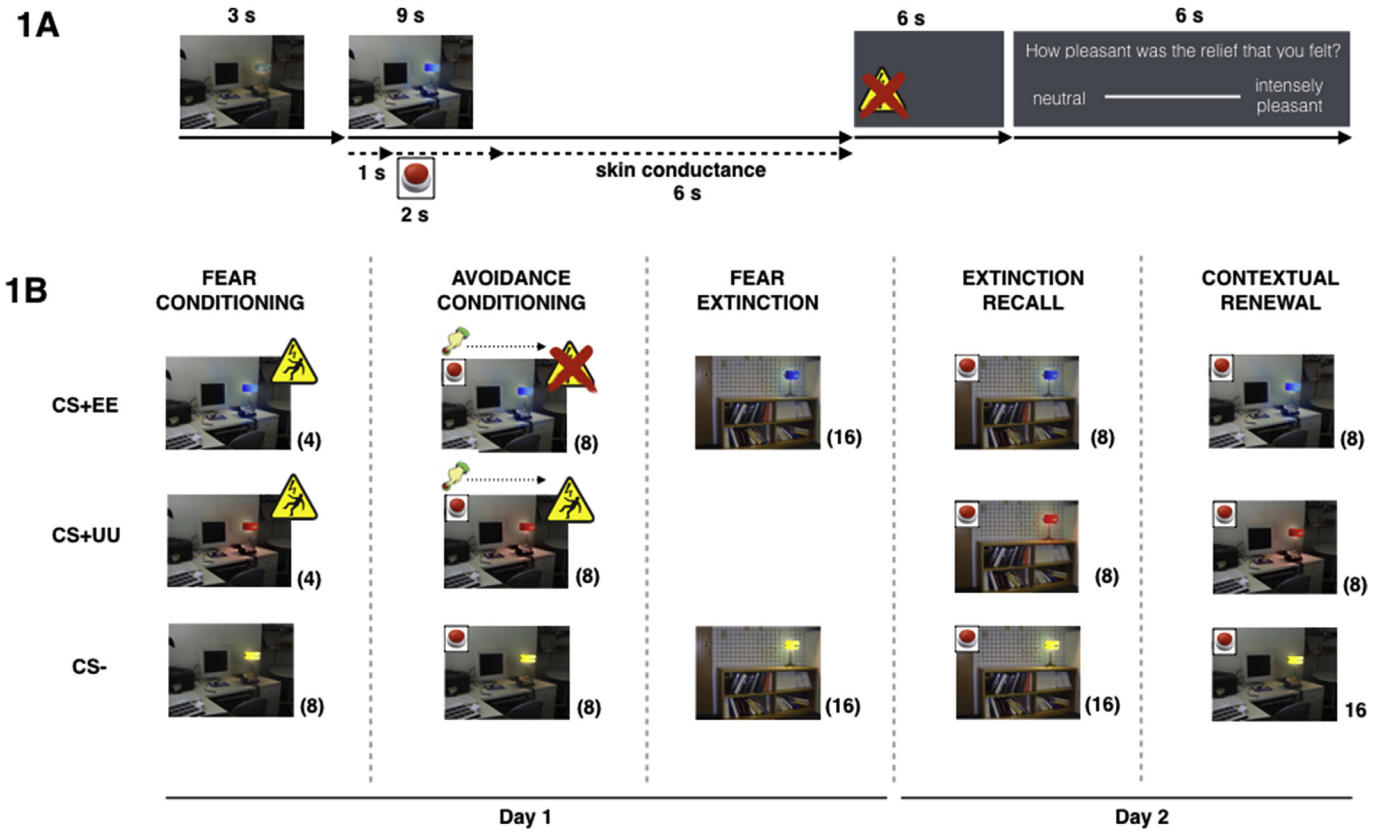


Fig. 1. Overview of the timeline of a successful avoidance trial and experimental design. 1A: Avoidance trials commenced with 3 s context (room picture), followed by 9 s lamp color. The red button appeared during 1–3 s following color onset. Skin conductance was measured during the remaining 6 s of color presentation. The relief pleasantness scale appeared 6 s after color offset and remained on the screen for 6 s **1B:** Two colors were paired with an aversive shock to the fingers during Fear Conditioning. All three colors included a red button during Avoidance Conditioning; clicking the computer mouse within the red button time window canceled the shock to one color (effective CS+, CS+EE), but not the other (unproductive CS+, CS+UU). Clicking was unnecessary to the nonconditioned control stimulus (CS-). Fear Extinction took place in a different context and included presentations of CS+EE (effective-and-extinguished CS+) and CS-, shock-free. Twenty-four hours later, all three colors were presented shock-free with the red button in the extinction context (Extinction Recall), followed by the conditioning context (Contextual Renewal). CS+UU refers to unproductive-and-unextinguished CS+. Colors were counterbalanced. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2. Methods

2.1. Participants

A total of 23 psychiatrically healthy participants (11 men and 12 women, mean age 24 years old, range 19–47) were recruited from the local community (the greater Boston area) and earned $90 for participation (sample size was based on fear extinction studies that used a similar design; Milad et al., 2005, 2007). They were told that the purpose of the research was to study emotional learning and memory. Psychiatric interviews were performed by trained psychologists (B.V. and I.L.), on the basis of the MINI International Neuropsychiatric Interview (Sheehan et al., 1998). Written informed consent was obtained in accordance with the requirements of the Partners Healthcare System Human Research Committee.

2.2. Stimuli and apparatus

Stimulus presentations were controlled by SuperLab software. Background contexts were two pictures of rooms with clearly distinctive features (an office room and a conference room). Both room pictures also contained a desktop lamp that would light up with a color: red, blue, or yellow (taken from Milad et al., 2005). On all trials, the lamp was not lit with any color during the first 3 s (context-only presentation), after which it illuminated in one of the three colors for the remaining presentation time (the conditional stimuli). Total CS durations were 6 s when the avoidance action was not available and 9 s when the action was available. Intertrial intervals were 15 s on average, with a range between 12 and 18 s.

The avoidance action was instructed to the participant prior to the avoidance conditioning phase and consisted of clicking the left button of the computer mouse that was placed near the dominant hand of the subject. Availability of the avoidance action was signaled by an avoidance cue, which consisted of a 2 s red button that appeared over the room pictures (starting at 1 s following CS onsets).

The unconditional stimulus (US) was a 500 ms mild electrical shock delivered through electrodes on the index and middle fingers of the non-dominant hand. It was generated by a Coulbourn Transcutaneous Aversive Finger Stimulator (E13-22), which was isolated from line current and powered by a 9-V dry cell battery attached to an adjustable step-up transformer. The minimum-maximum range was 0.2–4 mA. Before the start of the experiment, the participant set the shock intensity to a level that was "highly annoying but not painful". Participants were seated in an armchair in a room separate from the experimenter's room.

Skin conductance level (SCL) was measured using a BIOPAC Systems, Inc. (Goleta, CA) MP150 system, AcqKnowledge 3.9.2 and 4.0 software and a BIOPAC GSR100C Electrodermal Activity Amplifier. BIOPAC EL504 disposable adhesive electrodes were placed on the hypothenar surface of the non-dominant hand

10 mm apart. Event markers, transmitted to AcqKnowledge from SuperLab via a PCI-DIO24 digital I/O card and a BIOPAC STP100C digital interface, enabled precise synchronization of each CS onset with physiological recording of SCL.

Explicit expectancies of US occurrence were measured retrospectively by asking participants after each experimental phase to rate their expectancies of the US during each CS. A five-point scale was used, with the left end of the scale labeled as "certainly no shock" and the right end "certainly shock". Following the fear conditioning and fear extinction phases, participants were asked to rate their expectancies during the first and last presentation of each CS. Following the avoidance conditioning, extinction recall, and renewal phases, participants were asked to rate how much they were expecting to be shocked if they did press the button during each CS presentation, and if they did not.

Subjective ratings of relief pleasantness were recorded via a visual analogue scale (10 mm) on the computer screen with the left end labeled "Neutral" (invisible x-coordinate: −300) and the right end labeled "Extremely pleasant" (invisible x-coordinate: +300). The scale appeared 6 s following CS offsets without US, during all phases except familiarization and fear conditioning. The scale remained on the screen for 6 s and was operated by the computer mouse.

In addition to a standard set of personality questionnaires that is collected prior to each study in the lab for future purposes, individual differences in tolerance of distress were measured via the Distress Tolerance Scale (DTS; Simons & Gaher, 2005). The DTS is a 15-item self-report measure that examines one's perceived ability to tolerate emotional distress including questions related to tolerance, appraisal, absorption, and regulation. This measure has shown good internal consistency, as well as convergent and divergent validity (Simons & Gaher, 2005). The minimum-maximum range is 1 (low) to 5 (high), with scores ranging between 2.42 and 4.83 in the current experiment.

2.3. Procedure

Following mental health screening (MINI International Neuropsychiatric Interview, Sheehan et al., 1998) and questionnaire completion, participants were informed that the experiment would start with a **familiarization phase** that included all pictures but no shocks. This phase consisted of 1 presentation of each of the three lamp colors (CS) in each of the two rooms (context). Next, participants were asked how many rooms and lights they had seen, and received the following instructions: "From now on, you may or may not be shocked. If you receive a shock, try to see if there is a pattern associated with the shock." The **fear conditioning phase** started with a first block of 4 presentations of one CS that was always followed by the aversive US (CS+) and 4 presentations of another CS that was never followed by the US (CS-), followed by a second block in which another CS+ was presented 4 times, as well as the CS- (CSs counterbalanced). Upon completion of this phase, the experimenter guided the participants through the retrospective US-expectancy ratings.

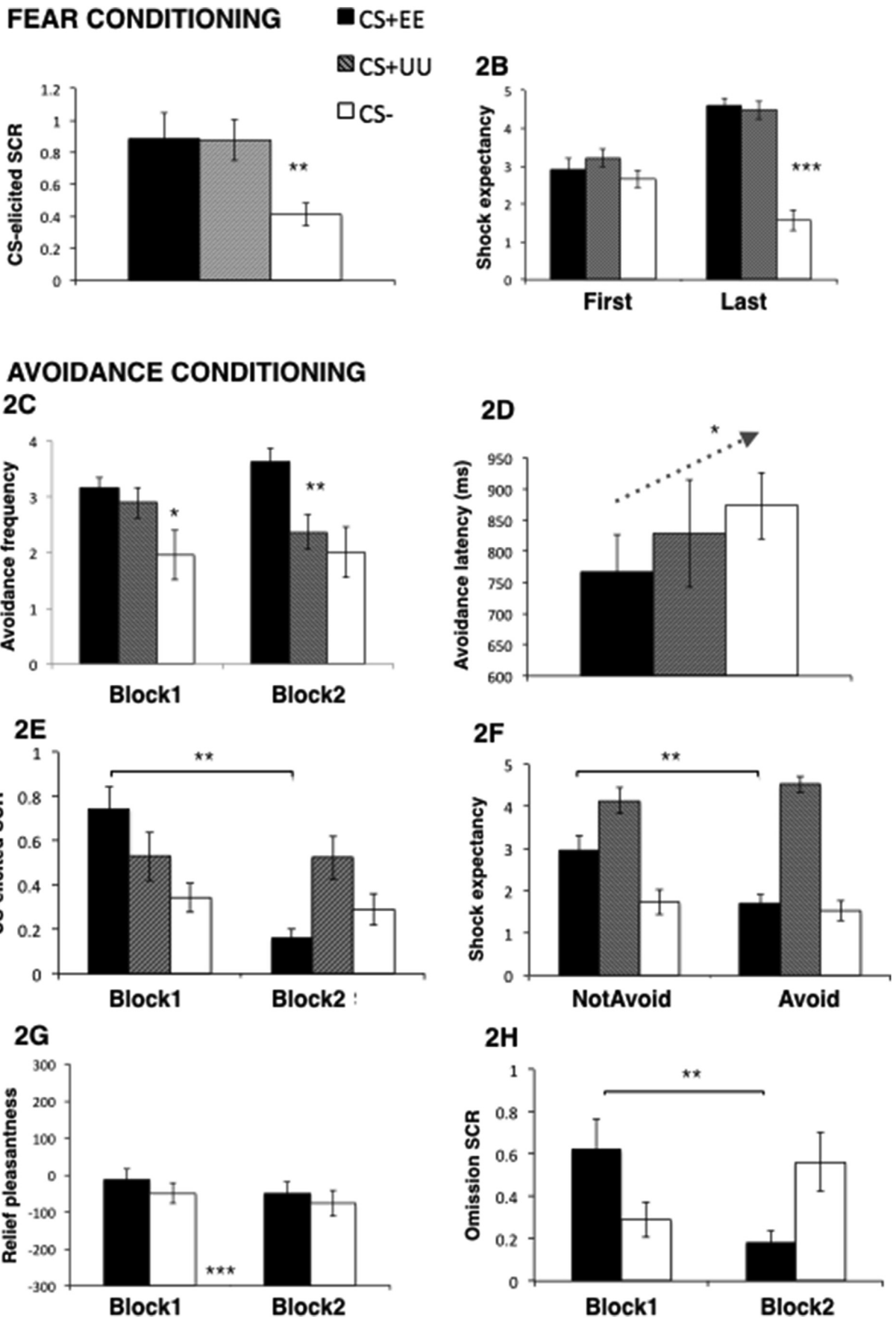
Then, the experimenter placed the mouse near the participant's dominant hand and explained that, in the next phase, clicking the left button during presentations of the avoidance cue (which was shown on the screen for illustrative purposes) could or could not cancel the shock at the end of the CS. In addition, the experimenter showed and explained the relief pleasantness scale and how to operate it via the computer mouse. The participants were asked to rate the pleasantness of the relief that they experienced *after* the foregoing picture, not during the picture. The **avoidance conditioning phase** consisted of 8 presentations of each CS (two CS+ and one CS-), which now had an extended duration of 9 s. One second following CS onset, the avoidance cue appeared on the screen for 2 s (signaling the availability of the avoidance action). Clicking the mouse button during the avoidance cue effectively canceled the shock at the end of one CS+ (CS+EE), but not the other (CS+UU). CS trials were intermixed during this phase. Afterwards, the expectancy questions were asked. During the **fear extinction phase**, the context changed and the CS+EE and the CS- were each presented 16 times for 6 s (cf. fear conditioning), always without the avoidance cue (response prevention) and never followed by the shock US. Following the expectancy rating questions, the experimental session ended.

The next day, participants returned to the same room. The experimenter asked some general questions that probed the declarative memory of the shock associations the day before, s/he mentioned that the participants may or may not receive shocks in the next phase, and s/he proceeded to instruct the monetary cost of avoidance clicking. Specifically, participants were told "You can still mouse-click the red button if it appears. However, from now on, clicking the red button will incur a monetary cost. Each time that you click the red button, we will deduct […] cents from your 90 dollar participation fee." The exact amount varied between participants ($0.01, $0.05, $0.10, $0.20, or $.0.40, evenly distributed across participants). Next, the **extinction recall phase** started, which was similar to the avoidance conditioning phase, but (1) no shocks were administered, (2) all CS presentations were in the extinction context, and (3) CSs were presented in separate blocks of 8 CS+EE and 8 CS+UU trials (order counterbalanced), and 8 CS- trials within each block. Following a small break during which the expectancy questions were asked, the **renewal phase** started, which was identical to the extinction recall phase, but all CS presentations were in the conditioning context and the block order could differ (counterbalanced). Following the expectancy rating questions, the experimental session ended.

2.4. Analyses

CS-elicited skin conductance reactivity (SCR) was calculated on a trial-by-trial basis by subtracting the average skin conductance level (SCL) during 2 s prior to each CS from the peak SCL during the 6 s CS window (on avoidance trials, the 6 s window started immediately after removal of the avoidance button). Omission-elicited SCR was calculated on trials that contained no US, by subtracting the average SCL during 2 s prior to CS offset from the peak SCL during the 6 s post-CS window. Negative changes were scored as zero and included in all analyses. The remaining positive values were square root transformed for reducing skewness of the distribution.

For all measures, we calculated averages of four consecutive trials per CS and entered these averages as blocks into repeated measures analyses of variance (RM-ANOVA). The reasons for averaging were missing relief ratings during avoidance conditioning on CS+EE trials with no avoidance actions, missing relief ratings during extinction (10), recall (5), and renewal (3), and the RM-ANOVA requirement to turn avoidance frequencies (0 or 1 per trial) into continuous variables. For reasons of consistency, we applied this averaging strategy across all experimental phases and measures (except retrospective US-expectancy ratings). Greenhouser-Geisser corrections were applied when Mauchly's test of sphericity was significant. Post-hoc comparisons were Bonferroni corrected within each RM-ANOVA model to protect against inflated type I errors. In a separate step in the analyses, distress tolerance scale scores were entered as covariate of interest into the RM-ANOVA's, in order to evaluate the influence of distress tolerance on the different measures across the experimental phases.


FEAR CONDITIONING
CS+EE
CS+UU
CS-
CS-elicited SCR
**
2B
Shock expectancy
***
First
Last
AVOIDANCE CONDITIONING
2C
Avoidance frequency
*
**
Block1
Block2
2D
Avoidance latency (ms)
*
2E
CS-elicited SCR
**
Block1
Block2
2F
Shock expectancy
**
NotAvoid
Avoid
2G
Relief pleasantness
***
Block1
Block2
2H
Omission SCR
**
Block1
Block2

3. Results

3.1. Shock intensity (Day 1)

Selected shock levels ranged between 0.6 and 4 mA, with a mean level of 1.84 (SD = 0.84). Distress tolerance correlated negatively with selected intensity of shock, r = -0.489, $p < 0.05$, but visual inspection of the scatter plot identified two outliers that drove the correlation (removing these outliers reduced the correlation to r = -0.12, $p = 0.62$).

3.2. Fear conditioning phase (Day 1)

Skin conductance reactivity (Fig. 2A). Conditioning was successful given that there was stronger reactivity to each CS+ compared to the CS-, as evidenced by a main effect of Stimulus (3) in a one-way repeated measures analysis of variance (RM-ANOVA), $F(2,40) = 11.10$, $p < 0.001$, $\eta_p^2 = 0.36$, and confirmed by post-hoc pairwise comparisons with CS-, p's < 0.01.

Retrospective ratings (Fig. 2B). Differential US-expectancy developed over the course of conditioning, as evidenced by a main effect of Stimulus, $F(2,44) = 25.81$, $p < 0.001$, $\eta_p^2 = 0.54$, that was qualified by a Stimulus * FirstLast interaction, $F(2,44) = 29.74$, $p < 0.001$, $\eta_p^2 = 0.58$, within a 3 (Stimulus) * 2 (FirstLast) RM-ANOVA. Post-hoc comparisons confirmed the absence of differences for the first conditioning trial, p's > 0.19, whereas CS+EE and CS+UU were both higher than CS- for the last trial, p's < 0.001, and not different from each other, $p = 1.00$.

3.3. Avoidance conditioning phase (Day 1)

Avoidance frequencies (Fig. 2C). Across blocks, participants learned to execute the avoidance action when it was effective (during CS+EE), and less so when it was unproductive (during CS+UU) or unnecessary (during CS-), as evidenced by a main effect of Stimulus, $F(1.45,31.98) = 8.97$, $p < 0.01$, $\eta_p^2 = 0.29$, that was qualified by a Stimulus * Block interaction, $F(2,44) = 14.6$, $p < 0.001$, $\eta_p^2 = 0.40$, within a 3 (Stimulus) * 2 (Block) RM-ANOVA. Post-hoc comparisons confirmed that avoidance frequency increased to CS+EE, $p < 0.01$, while it decreased to CS+UU, $p <$ .05. On Block 1, CS+EE and CS+UU were both higher than CS-, p's < 0.05, and not significantly different from each other, $p = 1.00$, indicating that the avoidance frequencies were initially influenced by prior CS-US associations. In Block 2, CS+EE was higher than both CS+UU and CS-, p's < 0.01, which were no longer different from each other, $p = 1.00$. This shows that the avoidance frequencies came under the influence of the consequences of the avoidance actions.

Avoidance reaction times (Fig. 2D). Avoidance reaction times were calculated on a trial-by-trial basis as the time difference between appearance of the button on the computer screen and clicking the mouse button (avoidance reaction). A one-way (CS) RM-ANOVA revealed a main effect of Stimulus, $F(2,32) = 4.52$, $p < 0.05$, $\eta_p^2 = 0.22$, that included a linear trend with increasing latencies from CS+EE over CS+UU to CS-, $F(1,16) = 11.12$, $p < 0.01$, $\eta_p^2 = 0.41$. This may indicate that the motivation to avoid was highest to the effective CS+EE, lower to the unproductive CS+UU, and lowest to the unnecessary CS-.

CS-elicited SCR (Fig. 2E). The avoidance action was always available during the first part of each CS. The remainder of each CS presentation was used to track avoidance-induced fear regulation effects. SCR decreased only to CS+EE, as indicated by a Stimulus * Block interaction, $F(2,42) = 15.69$, $p < 0.001$, $\eta_p^2 = 0.44$, within a 3 (Stimulus) * 2 (Block) RM-ANOVA, and confirmed by post-hoc comparisons that showed the expected decrease to CS+EE, $p < 0.001$. Meanwhile, SCR to CS+UU remained high, and SCR to CS- remained low, p's > 0.47. In Block 1, SCR was higher to CS+EE compared to CS-, $p < 0.01$. In Block 2, SCR to CS+EE was no longer distinguishable from CS-, $p = 0.44$, and lower than CS+UU, $p < 0.01$. This pattern of results confirms avoidance-based safety learning to the effective stimulus, CS+EE (cf. Vervliet & Indekeu, 2015).

Retrospective expectancy ratings (Fig. 2F). Participants gradually learned that the avoidance action cancelled the US to CS+EE, as indicated by a main effect of Stimulus, $F(2,44) = 63.10$, $p < 0.001$, $\eta_p^2 = 0.74$, qualified by an Avoidance * Stimulus interaction, $F(2,44) = 10.31$, $p < 0.001$, $\eta_p^2 = 0.32$, within a 2 (Avoidance: hypothetically avoid versus hypothetically not avoid) * 3 (Stimulus) RM-ANOVA. Post-hoc comparisons confirmed that US-expectancy was lower with versus without avoidance to CS+EE, $p < 0.01$, while there was no difference in the other CSs, p's > 0.27. Moreover, under conditions of hypothetical non-avoidance, CS+EE elicited higher US-expectancy than CS-, $p < 0.01$, while under conditions of hypothetical avoidance, US-expectancy was equally low, $p = 1.00$. US-expectancy during CS+UU, on the other hand, remained higher than CS+EE and CS-, p's < 0.001, under conditions of hypothetical avoidance.

Relief pleasantness ratings (Fig. 2G). Participants reported non-neutral levels of relief pleasantness following both CS+EE and CS- (CS+UU was always followed by the US and therefore never probed for relief). A one sample t-test showed that the average relief rating across stimuli and blocks was indeed higher than 'Neutral' (rating value of −300), $t(22) = 9.89$, $p < 0.001$, while a 2 (Stimulus) * 2 (Block) RM-ANOVA failed to reveal effects of Stimulus, $F(1,20) = 2.11$, $p = 0.16$, or interaction with Block, $F(1,20) = 0.07$.

Omission SCR (Fig. 2H). CS+EE offsets triggered skin conductance reactions that decreased across blocks, as indicated by a Stimulus * Block interaction, $F_{1,19} = 5.34$, $p < 0.05$, $\eta_p^2 = 0.22$, within a Stimulus (2) * Block (2) RM-ANOVA. Post-hoc comparisons confirmed that the interaction was driven by a significant decrease to CS+EE, $p < 0.01$, and no change to CS-, $p = 0.25$. Interestingly, adding relief pleasantness (averaged across CS+EE and CS- and blocks) as a co-variate to the RM-ANOVA revealed a main effect of relief pleasantness, $F_{1,18} = 5.13$, $p < 0.05$, $\eta_p^2 = 0.22$, indicating that higher levels of relief pleasantness were related to higher levels of omission SCR. This was confirmed by a separate correlational analysis between relief pleasantness and omission SCR (both averaged across CS+EE and CS-), $r = 0.48$, $p < 0.05$.

Correlations between relief pleasantness and shock-expectancy. In support of its prediction error properties, we observed that the level of relief pleasantness correlated significantly with retrospective ratings of shock-expectany under hypothetical avoidance, both for CS+EE ($r = 0.57$, $p = 0.005$) and for CS- ($r = 0.46$, $p = 0.027$), also when controlling for the frequency of avoidance responding, respectively, CS+EE: $r = 0.56$, $p = 0.006$, CS-: $r = 0.48$, $p = 0.023$.

Fig. 2. Fear conditioning and avoidance conditioning. Black bars represent CS+EE, gray bars CS+UU and white bars CS-. **2A-B:** SCR and US-expectancies were higher to both CS+EE and CS+U, compared to CS-, indicating successful conditioning. **2C:** Avoidance actions were more frequent during the two CS+ versus CS- (Block 1), and became more specific to CS+EE (Block 2). **2D:** Avoidance latency increased from CS+EE over CS+UU to CS-. **2E-F:** SCR and US-expectancies decreased to CS+EE (post-avoidance window), indicating avoidance-based safety learning. **2G:** Relief pleasantness was significantly higher than "Neutral" (−300), but not differently for CS+EE and CS-. **2H:** Omssion SCR decreased to CS+EE offsets. Errors bars represent standard errors of the mean; * represents $p < 0.05$; ** represents $p < 0.01$; *** represents $p < 0.001$. See text for further details.

3.4. Fear extinction phase (Day 1)

CS-elicited SCR (Fig. 3A). The context change abruptly abolished the differential skin conductance reaction to CS+EE and CS-, leaving no room for a gradual decrease that normally characterizes extinction, resulting in a non-significant Stimulus * Block interaction, $F(2.10, 41.95) = 1.04$, $p = 0.38$, and a non-significant effect of Stimulus, $F(1,20) = 1.31$, $p = 0.27$, within a 2 (Stimulus) * 4 (Block) RM-ANOVA. A significant effect of Block did indicate an overall decrease in skin conductance reactivity, $F(3,60) = 3.59$, $p < 0.05$, $\eta_p^2 = 0.15$.

Retrospective expectancy ratings (Fig. 3B). Differential expectancy followed the typical extinction course, as indicated by main effects of Stimulus, $F(1,22) = 16.33$, $p < 0.01$, $\eta_p^2 = 0.43$, and First-Last, $F(1,22) = 55.73$, $p < 0.001$, $\eta_p^2 = 0.72$, qualified by a Stimulus * FirstLast interaction, $F(1,22) = 17.80$, $p < 0.001$, $\eta_p^2 = 0.45$, within a 2 (Stimulus) * 2 (FirstLast) RM-ANOVA. Post-hoc comparisons confirmed that the CS+EE/CS- difference was significant for the first trial, $p < 0.001$, and no longer for the last trial, $p = 0.33$.

Relief pleasantness ratings (Fig. 3C). Relief pleasantness decreased gradually over the course of extinction, as evidenced by a main effect of Block, $F(1.28,21.73) = 5.69$, $p < 0.01$, $\eta_p^2 = 0.25$, but not at different rates for CS+EE and CS-, Stimulus * Block interaction, $F(1.47,25.05) = 0.19$, $p = 0.76$, Stimulus, $F(1,17) = 1.40$, $p = 0.25$, within a 2 (Stimulus) * 4 (Block) RM-ANOVA.

Omission SCR. A 2 (Stimulus) * 4 (Block) RM-ANOVA did not reveal a Stimulus effect, a Block effect or a Stimulus * Block interaction (F's < 1.95, p's > 0.13). Adding relief pleasantness (averaged across stimuli and blocks of extinction) as co-variate did not change the pattern of results.

3.5. Extinction recall phase (Day 2)

Avoidance frequency. Only five participants (2 $0.40, 1 $0.20, 1 $0.05, and 1 $0.01) clicked the avoidance button during recall, for a total of 14 clicks. A one sample t-test revealed that the average clicking frequency across the whole group ($M = 0.67$; $SD = 1.35$) was significantly higher than zero, $t(20) = 2.26$, $p < 0.05$. A one-way ANOVA with Cost as between-subjects factor (5 levels) revealed no effect of Cost on avoidance frequency during recall, $F(4,16) = 1.49$, $p = 0.25$.

CS-elicited SCR (Fig. 3D). SCR was first higher to CS+EE and CS+UU compared to CS-, and then extinguished over blocks during the recall phase, as indicated by a Stimulus * Block interaction, $F(2, 40) = 4.50$, $p < 0.05$, $\eta_p^2 = 0.18$, within a 3 (Stimulus) * 2 (Block) RM-ANOV, with main effects of Block, $F(1,20) = 24.16$, $p < 0.001$, $\eta_p^2 = 0.55$, and Stimulus, $F(2,40) = 6.39$, $p < 0.01$, $\eta_p^2 = 0.24$. Post-hoc analyses confirmed that SCR to CS+EE and CS+UU were both higher compared to CS- on the first block, p's < 0.05, and that SCR to both CS+EE and CS+UU decreased from the first to the second block, p's < 0.01.

Retrospective expectancy ratings (Fig. 3E). A 3 (Stimulus) * 2 (N/A: hypothetical avoid versus hypothetical not avoid) RM-ANOVA revealed a main effect of Stimulus, $F(1.44,31.59) = 13.3$, $p < 0.001$, $\eta_p^2 = 0.38$, and a main effect of N/A, $F(1,22) = 4.64$, $p < 0.05$, $\eta_p^2 = 0.17$, but no Stimulus * N/A interaction, $F(2,44) = 2.16$, $p = 0.13$. Post-hoc comparisons revealed that ratings for CS+UU were higher than ratings for CS+EE, $p < 0.05$, which where both higher than CS-, p's < 0.01.

Relief pleasantness ratings (Fig. 3F). Participants reported higher relief to CS+UU than to CS-, which subsequently decreased over the course of recall test trials, as evidenced by a main effect of Stimulus, $F(2,38) = 5.25$, $p < 0.05$, $\eta_p^2 = 0.22$, a main effect of Block, $F(1,19) = 12.54$, $p < 0.01$, $\eta_p^2 = 0.40$, and a Stimulus * Block interaction, $F(2,38) = 3.61$, $p < 0.05$, $\eta_p^2 = 0.16$, within a 3 (Stimulus) * 2 (Block) RM-ANOVA revealed. Post-hoc comparisons showed that this interaction was driven by higher relief to CS+UU than to CS- on Block 1, $p < 0.05$, but no longer on Block 2, $p = 0.41$.

Omission SCR. Averaged across all CSs, omission SCRs decreased from Block 1 to Block 2, but there were no differences between the CSs, as indicated by a significant main effect of Block, $F(1,20) = 5.06$, $p < 0.05$, $\eta_p^2 = 0.20$, in the absence of a main effect of Stimulus or a Stimulus * Block interaction, F's < 0.85, p's > 0.44, within a 3 (Stimulus) * 2 (Block) RM-ANOVA (Block 1: $M_{CS+EE} = 0.34$, $SD = 0.29$; $M_{CS+UU} = 0.40$, $SD = 0.26$; $M_{CS-} = 0.30$, $SD = 0.26$; Block 2: $M_{CS+EE} = 0.21$, $SD = 0.26$; $M_{CS+UU} = 0.26$, $SD = 0.37$; $M_{CS-} = 0.24$, $SD = 0.32$). Adding relief as a co-variate to the RM-ANOVA model did not change the pattern of results.

3.6. Renewal phase (Day 2)

Avoidance frequency. Only two participants ($0.40 and $0.05 cost) clicked the avoidance button during renewal, for a total of 5 clicks. A one sample t-test revealed that the group average of clicking frequency ($M = 0.24$; $SD = 0.89$) was not significantly different from zero, $t(20) = 1.23$, $p = 0.23$.

CS-elicited SCR (Fig. 3G). Surprisingly, we found no evidence for renewal of SCR, with a 3 (Stimulus) * 2 (Block) RM-ANOVA revealing only a main effect of Block, $F(1,20) = 6.53$, $p < 0.05$, $\eta_p^2 = 0.25$, but no main effect of Stimulus, $F(2,40) = 0.64$, $p = 0.53$, nor a Block * Stimulus interaction, $F(2,40) = 0.70$, $p = 0.50$.

Retrospective expectancy ratings (Fig. 3H). Contextual renewal of differential US-expectancy was evidenced by a main effect of Stimulus, $F(1.29,28.28) = 16.06$, $p < 0.001$, $\eta_p^2 = 0.38$, a main effect of N/A, $F(1,22) = 8.02$, $p < 0.05$, $\eta_p^2 = 0.27$, and a significant Stimulus * N/A interaction, $F(2,44) = 4.18$, $p < 0.05$, $\eta_p^2 = 0.16$, within a 3 (Stimulus) * 2 (N/A: hypothetical avoid versus hypothetical not avoid) RM-ANOVA. Post-hoc comparisons revealed higher ratings to CS+EE and CS+UU than to CS- under hypothetical non-avoidance, p's < 0.01, while CS+UU was higher than CS+EE in a marginally significant way, $p = 0.06$. Under hypothetical avoidance, CS+UU was significantly higher than both CS+EE and CS-, p's < 0.01, which were not distinguishable from each other, $p = 0.31$.

Relief pleasantness ratings (Fig. 3I). Participants reported higher relief to CS+EE and CS+UU than to CS-, which subsequently decreased over the course of recall test trials, as evidenced by a main effect of Stimulus, $F(2,36) = 9.64$, $p < 0.001$, $\eta_p^2 = 0.35$, a main effect of Block, $F(1,18) = 23.11$, $p < 0.001$, $\eta_p^2 = 0.56$, and a Stimulus * Block interaction, $F(1.45,26.01) = 5.84$, $p < 0.05$, $\eta_p^2 = 0.25$, within a 3 (Stimulus) * 2 (Block) RM-ANOVA. Post-hoc comparisons showed that the interaction was driven by a significant difference between CS+EE and CS- on Block 1, $p < 0.05$, that was no longer present on Block 2, $p = 1.00$, while the difference between CS+UU and CS- remained significant throughout Block 1 and 2, p's < 0.01.

Omission SCR. Averaged across all CSs, omission SCRs tended to decrease from Block 1 to Block 2, but there were no differences between the CSs, as indicated by a marginally significant main effect of Block, $F(1,20) = 4.03$, $p = 0.058$, $\eta_p^2 = 0.17$, in the absence of a main effect of Stimulus or a Stimulus * Block interaction, F's < 0.43, p's > 0.65, within a 3 (Stimulus) * 2 (Block) RM-ANOVA (Block 1: $M_{CS+EE} = 0.30$, $SD = 0.26$; $M_{CS+UU} = 0.30$, $SD = 0.24$; $M_{CS-} = 0.25$, $SD = 0.27$; Block 2: $M_{CS+EE} = 0.23$, $SD = 0.33$; $M_{CS+UU} = 0.17$, $SD = 0.18$; $M_{CS-} = 0.21$, $SD = 0.27$). Adding relief as a co-variate to the RM-ANOVA model did not change the pattern of results.

3.7. Covariate effects of distress tolerance scale (DTS) scores

In order to evaluate effects of DTS on the various measures and across the experimental phases, we added DTS scores as covariate of interest to the RM-ANOVAs as reported above. In view of our a

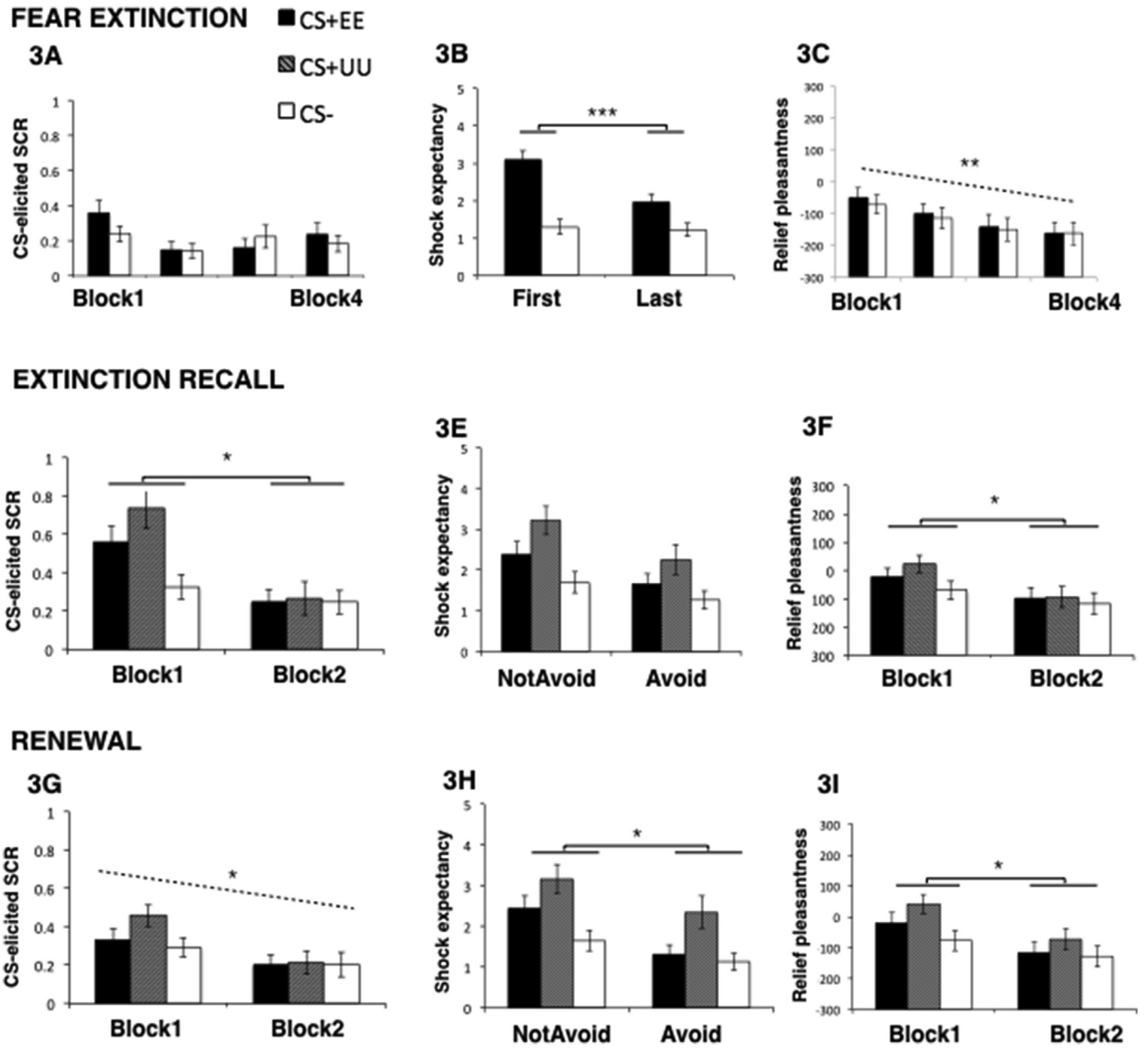
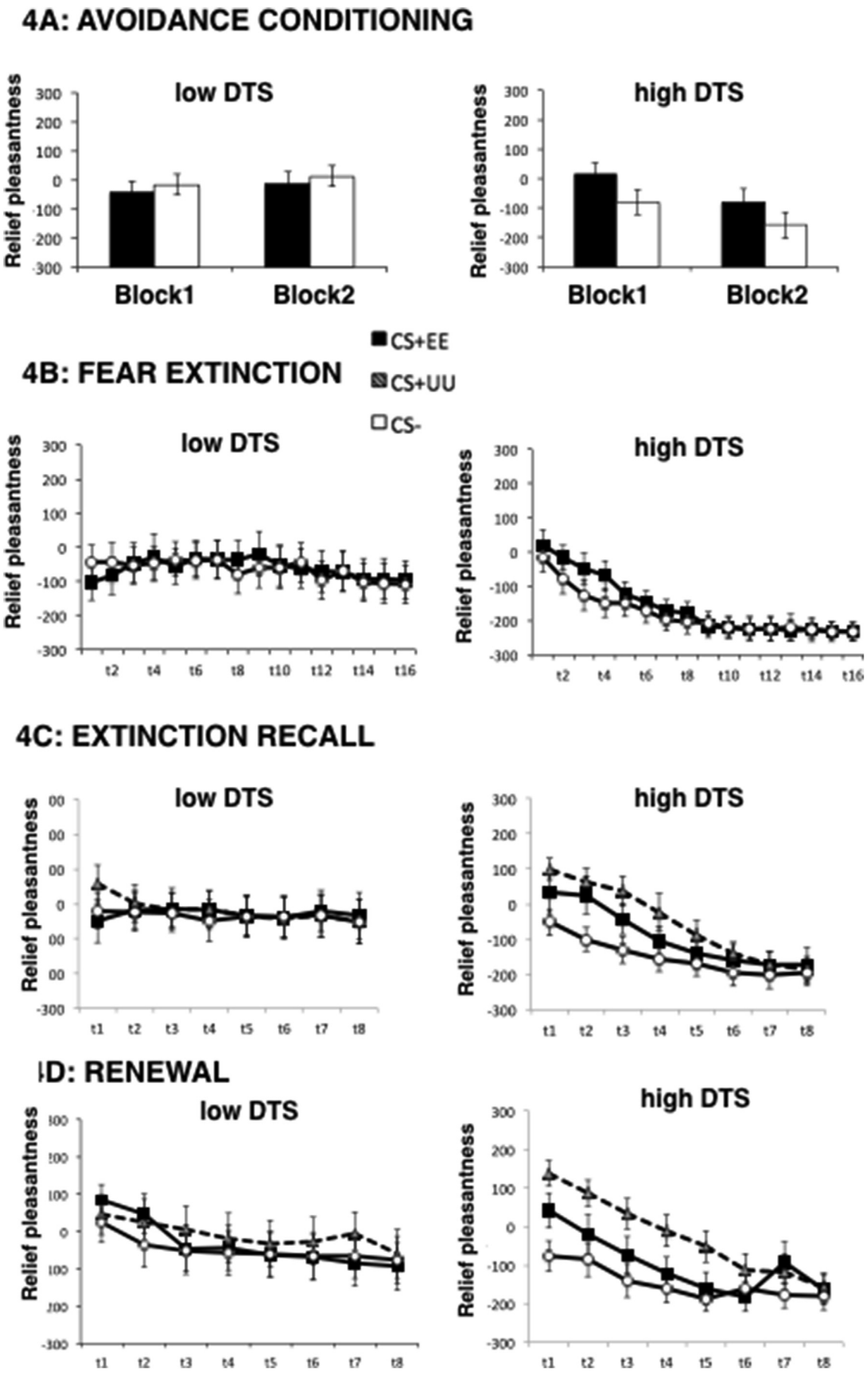


Fig. 3. Fear extinction, recall and renewal. Black bars represent CS+EE, gray bars CS+UU and white bars CS-. The Y-axes of the relief pleasantness graphs (2C, 2F, 2I) represent the computer screen coordinates of the relief pleasantness scale, where −300 corresponds to 'Neutral' and +300 to 'Extremely pleasant'. **3A-C:** Extinction learning was evident in US-expectancies but not in SCR; relief ratings showed an overall decrease across blocks (main effect of Block, dashed line). **3D-F:** Early recall (Block 1) showed CS-specific SCR and relief pleasantness that subsequently extinguished (Block 2). CS-specific US-expectancies were evident both under non-avoidance and avoidance questions (main effect of Stimulus). **3G-I:** Renewal was not evident in SCR. CS-specific US-expectancies were more expressed under non-avoidance compared to avoidance questions. Relief pleasantness ratings were CS-specific during early renewal (Block 1) and subsequently extinguished (Block 2). Errors bars represent standard errors of the mean; * represents $p < 0.05$; ** represents $p < 0.01$; *** represents $p < 0.001$. See text for further details.

priori predictions, we report the effects on relief ratings first.

Relief pleasantness ratings (Fig. 4). Overall, DTS had a significant influence on the course of relief ratings across the different experimental phases. During Avoidance Conditioning, low DTS participants reported chronically higher levels of relief pleasantness (Fig. 4A), as evidened by a DTS * Block interaction, $F(1,18) = 4.44$, $p < 0.05$, $\eta_p^2 = 0.20$, and a main effect of DTS, $F(1,18) = 8.33$, $p < 0.05$, $\eta_p^2 = 0.32$. During Fear Extinction, the relief ratings followed the predicted extinction course in high DTS participants, but a non-differential, chronic course in low DTS participants (Fig. 4B). Adding DTS scores as a covariate rendered the Stimulus * Block interaction significant, $F(1.76,28.16) = 7.94$, $p < 0.01$, $\eta_p^2 = 0.33$, and revealed interactions of DTS with Block, $F(1.44,22.96) = 10.15$, $p < 0.01$, $\eta_p^2 = 0.39$, and with Stimulus * Block, $F(1.76,28.16) = 8.24$, $p < 0.01$, $\eta_p^2 = 0.34$, as well as a marginally significant main effect of DTS, $F(1,16) = 3.93$, $p < 0.07$, $\eta_p^2 = 0.20$. During Extinction Recall, the relief ratings decreased progressively in distress tolerant participants, but remained high in participants intolerant of distress (Fig. 4C), as evidenced by an interaction of DTS with Block, $F(1,17) = 9.44$, $p < 0.01$, $\eta_p^2 = 0.36$, and a main effect of DTS, $F(1,17) = 5.55$, $p < 0.05$, $\eta_p^2 = 0.25$. During Renewal, the relief ratings followed the predicted re-extinction course in high DTS


4A: AVOIDANCE CONDITIONING
low DTS
high DTS
Relief pleasantness
Block1
Block2
CS+EE
CS+UU
CS-
4B: FEAR EXTINCTION
4C: EXTINCTION RECALL
D: RENEWAL

participants, but a non-differential, elevated course in low DTS participants (Fig. 4D), as evidenced by an interaction of DTS with Block, $F(1,16) = 4.59$, $p < 0.05$, $\eta_p^2 = 0.22$, and with Stimulus * Block, $F(2,32) = 8.62$, $p < 0.01$, $\eta_p^2 = 0.35$.

Removing the two outliers that spurred the correlation between DTS and shock intensity did not change the statistical significance levels of the results above, except for the relief ratings in the Avoidance conditioning phase. Removal of the two outliers weakened the DTS * Block interaction, $F(1,16) = 3.54$, $p < 0.08$, $\eta_p^2 = 0.18$, while at the same time rendering the main effect of Stimulus significant, $F(1,18) = 5.25$, $p < 0.05$, $\eta_p^2 = 0.23$, thereby providing evidence for the predicted higher levels of relief pleasantness following CS+EE compared to CS- (see Fig. 2F).

Avoidance frequency (Fig. 5A). We found no significant effects of DTS in any of the avoidance phases, but low DTS participants tended to avoid more diffusely across the three CSs during Avoidance Conditioning. We followed this up by a median-split DTS (2) * Stimulus (3) ANOVA, which did reveal a marginally significant DTS * Stimulus interaction, $F(1.44, 28.83) = 3.65$, $p = 0.052$, $\eta_p^2 = 0.15$.

Retrospective expectancy ratings (Fig. 5B–C). Extinction learning was more pronounced in high DTS participants during Fear Extinction (Fig. 5B), as evidenced by an interaction of DTS with FirstLast, $F(1,20) = 10.29$, $p < 0.01$, $\eta_p^2 = 0.34$, and a marginally significant interaction with Stimulus * FirstLast, $F(1,20) = 3.78$, $p < 0.07$, $\eta_p^2 = 0.16$, as well as a marginally significant main effect of DTS, $F(1,20) = 3.98$, $p = 0.06$, $\eta_p^2 = 0.17$. Also, participants with higher DTS reported more differential shock-expectancy during Extinction Recall (Fig. 5C), as evidenced by an interaction of DTS with Stimulus, $F(1.50,29.92) = 3.83$, $p < 0.05$, $\eta_p^2 = 0.16$.

CS-elicited SCR. We found no significant effects of DTS in any of the phases.

Omission SCR. We found no significant effects of DTS in any of the phases.

4. Discussion

This study tested in healthy individuals a newly developed avoidance paradigm to track the temporal dynamics of relief and to probe the extinction and recovery of avoidance. We found that subjective ratings of relief pleasantness followed the hypothetical course of prediction error signaling, but only in participants with higher tolerance of distress. Low distress tolerance, on the other hand, resulted in generalized and chronic levels of relief pleasantness that were less modulated by actual contingencies of the US and its omissions. Following fear extinction under response prevention, avoidance frequencies showed little recovery during delayed testing, whereas fear and relief indices increased in both the extinction and conditioning context (skin conductance reactivity, retrospective ratings of US-expectancy, trial-by-trial ratings of relief pleasantness), and re-extinguished subsequently. Together, these results provide experimental validation of the novel avoidance paradigm and support relief pleasantness ratings as a proxy for reward PE signaling over the course of avoidance conditioning and fear extinction. Given that intolerance of distress has been associated with a wide range of psychopathologies (Leyro, Zvolensky, & Bernstein, 2010), including anxiety (Keough et al., 2010), the present results also add to the clinical relevance of the new paradigm and suggest that careful examination of relief dynamics in anxiety patients may reveal mechanistic deficits underlying pathological avoidance behavior and deviant fear extinction.

The learning challenge in the new avoidance paradigm concerns figuring out *when* a single avoidance action is effective, rather than learning *which* avoidance action is effective. Avoidance frequencies confirmed that participants learned to execute the avoidance action when it was effective (during CS+EE), and less so when it was unproductive (during CS+UU) or unnecessary (during CS-). This selectivity tended to be less pronounced in participants with lower tolerance of distress (although the statistical effect was only marginally significant, $p = 0.052$). A proclivity to generalize effective avoidance actions towards situations in which they are unnecessary and/or unproductive may contribute to the development of maladaptive avoidance patterns and can be studied experimentally via the current paradigm. Moreover, because the avoidance action does not terminate the CS in this protocol, we could simultaneously track the development of action—noUS learning by focusing on the time window between the avoidance action and CS offset (cf. Vervliet & Indekeu, 2015). As expected, skin conductance reactivity decreased following avoidance actions that were effective (CS+EE) versus unproductive (CS+UU), a pattern that was paralleled by retrospective US-expectancy ratings. These results corroborate earlier suggestions that safety learning and fear regulation are centrally involved in the conditioning of avoidance actions (Delgado et al., 2009; Lovibond, Chen, Mitchell, & Weidemann, 2013).

Avoidance conditioning was followed by a fear extinction phase during which the avoidance action was unavailable, similar to the response prevention and extinction technique that is at the heart of exposure-based treatments of anxiety-related disorders. In essence, these treatments work by exposing a patient to the feared situations that s/he would otherwise avoid, hence providing opportunities to learn that these situations are actually safe. In the current experiment, retrospectively reported US-expectancies did indeed decrease from the first to the last extinction trial. Differential SCR, on the other hand, deteriorated immediately. This may result from the abrupt context change at the start of extinction, a finding that is not uncommon in SCR-based human fear conditioning research (Vervliet, Vansteenwegen, & Hermans, 2010; Haesen & Vervliet, 2015). On the other hand, the ratings of relief pleasantness did follow the hypothesized PE curve over the course of extinction, particularly in participants with higher tolerance of distress. It would have been interesting to connect the relief ratings, viewed here as a proxy for the putative teaching signal (PE), to the individual rates of extinction learning in the current experiment, but this was impossible due to the failure in SCR and the absence of trial-by-trial US-expectancy ratings. Interestingly, the retrospective ratings of US-expectancy regarding the first and last extinction trial did reveal a more pronounced extinction effect in participants with higher tolerance of distress, suggestive of differences in extinction learning rates indeed. We speculate that detailed examination in anxiety patients could reveal a dysregulation of relief PE signaling that may relate to impairments of fear extinction often reported in the literature (Duits et al., 2015).

The long-term success of fear extinction depends on an ability to recall extinction memories, which may also influence the tendency to re-engage in avoidance actions. A 24 h follow-up test in the extinction context revealed a return of fear to CS+EE with low levels of avoidance. The level of SCR to the extinguished CS+EE was

Fig. 4. Influence of distress tolerance on the dynamics of relief pleasantness. Low DTS (left panels) and high DTS (right panels) are median-split groups based on the distress tolerance scale scores. Results are shown to illustrate the directions of the effects obtained from RM-ANCOVAs with DTS as covariate of interest (see text). The Y-axes represent the computer screen coordinates of the relief pleasantness scale, where −300 corresponds to 'Neutral' and +300 to 'Extremely pleasant'. Black bars represent CS+EE, gray bars CS+UU and white bars CS-. Errors bars represent standard errors of the mean.

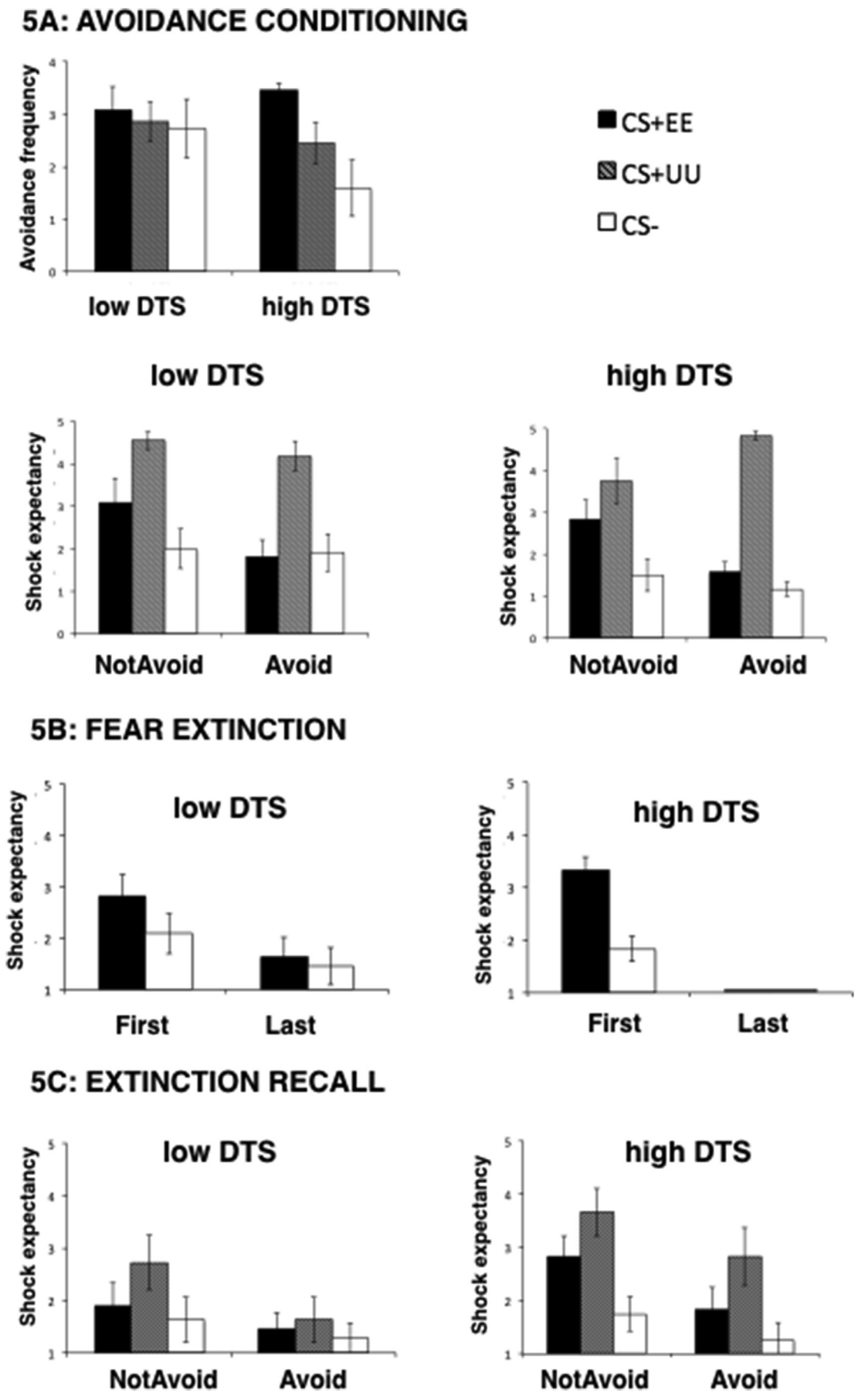


Fig. 5. Influence of distress tolerance on avoidance frequencies and retrospective shock-expectancies. Low DTS and high DTS are median-split groups based on the distress tolerance scale scores. Results are shown to illustrate the directions of the effects obtained from RM-ANCOVAs with DTS as covariate of interest (see text). Black bars represent CS+EE, gray bars CS+UU and white bars CS-. Errors bars represent standard errors of the mean.

indistinguishable from the non-extinguished CS+UU, indicating no savings of extinction. This is remarkable, because there was no differential SCR in the extinction context to begin with (Day 1). Possibly, the insertion of the avoidance button into the extinction context on Day 2 may have signaled potential threat (Engelhard, van Uijen, van Seters, & Velu, 2015; Vervliet & Indekeu, 2015). In addition, the monetary cost that we added to the avoidance action may have biased participants towards non-avoidance, despite the threat. This would have resulted in increased levels of fear that override any extinction savings. This explanation is supported by (1) the regular observation of extinction savings in a highly similar protocol that does not include avoidance (e.g., Milad et al., 2005, 2007), and (2) unpublished pilot data (N = 10) from our lab where avoidance rates were robust during follow-up testing when no monetary cost was involved. Future studies could directly compare the effects of cost versus no cost on avoidance rates, and compare return of fear levels under availability of avoidance or not.

We observed that individual differences in distress tolerance influenced the regulation of self-reported pleasantness of relief over the course of avoidance conditioning and fear extinction. Distress tolerance is generally thought to impact on the evaluation and expected consequences of exposure to aversive stimuli and to influence adaptive and maladaptive behavioral responding (Leyro et al., 2010). It is surprising to see, therefore, that this individual differences factor has never been evaluated in the context of fear conditioning, extinction, or avoidance, despite its well established role as a risk and maintenance factor in a wide range of psychopathologies, including anxiety (Keough et al., 2010; Leyro et al., 2010). We found that relief reactions to US omissions were less related to actual contingencies of the US and its omissions in participants with lower tolerance of distress. Rather, they seemed to report elevated relief following any CS termination that was not followed by US. Arguably, their regulation of relief was determined more by the expected *consequences* of being exposed to aversive shocks than by the expected *probability* of receiving the shock. These results prompt further research into the roles of relief regulation and distress tolerance with regard to fear conditioning processes on the one hand, and exposure-based treatment principles on the other hand. We also want to reiterate here that such relief dysregulations are in line with our working theory on problematic avoidance development. We propose that chronic, sustained levels of relief, possibly due to impaired action-safety learning, produce over-reinforcements of foregoing actions that lead to generalized, habitized and/or excessive avoidance. Further research on the interplay between distress tolerance, relief pleasantness and avoidance within the context of clinical anxiety has the potential to deepen our understanding of the mechanisms that push adaptive into maladaptive avoidance.

5. Limitations

The current study had a number of limitations. First, we did not find the expected effect of distress tolerance on the frequency of avoidance in a covariate analysis. If relief pleasantness is the prime reinforcer of avoidance, and given that distress tolerance influenced ratings of relief, we would have expected distress tolerance to also influence avoidance frequencies. Nevertheless, the average frequencies per CS did suggest an effect of distress tolerance, which was supported by a marginally significant interaction with CS within a median-split analysis based on distress tolerance scores. Adding more trials to the avoidance conditioning phase could give more power to detect effects of distress tolerance. Second, there was a relatively large amount of missing data in the relief ratings, which hindered trial-by-trial analyses of relief dynamics in the various experimental phases. Prior familiarization and/or specified instructions regarding the use of the relief scale seem warranted for future studies. Third, it is presently unclear to what extent relief pleasantness would provide a better proxy for the valence-signed reward PE than, e.g., ratings of relief intensity or pleasantness ratings of shock omission. More research is needed to establish a valid subjective correlate of valence-signed reward PE. Fourth, shock-expectancies were rated retrospectively after each phase in the experiment, rather than online during actual CS presentations. This was done in order not to burden the participant too much with inserting expectancy ratings in between avoidance decisions and relief pleasantness ratings. However, it would have been interesting to measure the temporal dynamics of shock-expectancy along with relief pleasantness and examine their interaction. Online shock-expectancy ratings often increase during a CS- after a context change (Vervliet, Baeyens, et al., 2013; Vervliet, Craske, et al., 2013), while the retrospective ratings remained low in the current study (see also Vansteenwegen et al., 2005). Discordance with high levels of online ratings of relief pleasantness may thus primarily reflect a measurement issue rather than indicating differences in dynamics between expectancy and relief. Finally, the participant sample consisted of community members that were screened for mental health and major medical conditions. It is not yet clear to what extent the current results will extend to patient populations.

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